UNIDIRECTIONAL BLOCKS AND ECTOPIC FOCI INDUCED BY COUPLING AN ISHEMIC AND A NORMAL VENTRICULAR CELL

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Abstract-**This study deals with the behavioural zones of a system composed of a normal myocardial cell (NC) coupled by an electric resistance R to an ischemic, depolarized by an added steady current I, (DC) cell. When varying I, we evidenced 3 levels of stationary solutions corresponding to low (L), medium (M) and high (H) values of the resting potential. In the L zone, we evidenced unidirectional block (UB) effects with respectively 2 (R=20) or 1 (R=50) thresholds of depolarization. From 2 Hopf bifurcation points, emerge branches of periodic solutions corresponding to ectopic foci (EF) coexisting with L or M types of resting potential. In these zones, we found again UB effects with, in case of propagation, a locking of the system to a rythmic activity. This theoretical study represents a unified approach of some types of UB and EF related to ischemia.**

I. INTRODUCTION

It is commonly accepted that unidirectional blocks (UB) and ectopic foci (EF) are major causes of ventricular fibrillation triggering. Because of the complexity of the asociated experimental techniques, many important aspects of these phenomena remain subjects of debates. Joyner [1], Quan and Rudy [2] and others used mathematical models to answer some of these conjectures. Nevertheless, many aspects remained presently unsolved. The purpose of this paper is to apply non linear analysis mathematical methods to study the effects of a depolarized ischemic cell on a normal cell. Emphasis is given on the interplay between the degree of ischemia and the value of the coupling resistance in the generation of UB and EF in this system.

II.METHODOLOGY

We consider a two cells system composed of a normal cell (NC,1) coupled with a depolarized ischemic cell (DC, 2) by an electric resistance R. Ischemia of cell 2 is simulated by adding a steady bias current I. Reconstruction of the single cell action potential (AP) was performed by using Van Capelle and Durrer (VCD) model [3], [4]. A detailed study of the various behavioural zones of the system when varying I and R was performed using continuation-bifurcation methods [5].

The results are represented in bifurcation diagrams with I in abcissa (internal units of the VCD model) and the amplitude of the equilibrium potentials (same type of units) in ordinate. Lines stand for stationary solutions, either stable (continuous line) or unstable (dashed lines). For such determined pertinent values of I and R, the two cells system is simulated numerically using an automatic controlled step length algorithm based on a 4th order Ruange-Kutta method as previously reported [4].

III. RESULTS

Figures 1 and 2 respectively show equilibrium potential of cells 1 and 2 when varying I. From Hopf bifurcation points 4 and 7 grow two periodic branches of solutions PB4 and PB7 (not shown).

The dissymmetry between resting potential of NC cell 1 and DC cell 2 results in a correspondent dissymmetry in thresholds for propagation when depolarization is applied to cell 1 (depo1) or to cell 2 (depo2). Thus, we found a window of depolarization values between 9 and 11 where, for the same depolarization, depo2 induces a propagation (fig. 3) and depo1 a block (fig. 4).

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Abstract

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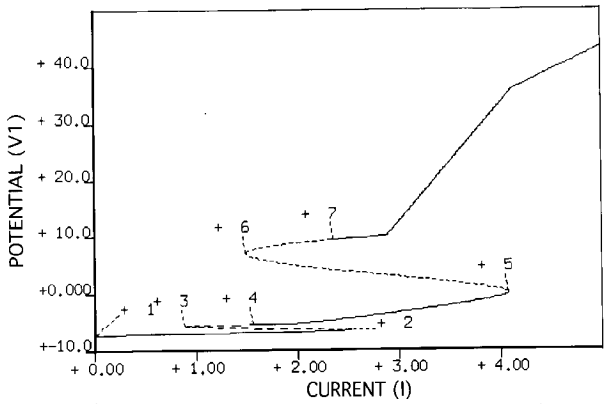

Fig. 1. Bifurcation diagram showing stationary potentials of cell 1 (V1) versus I for R=20

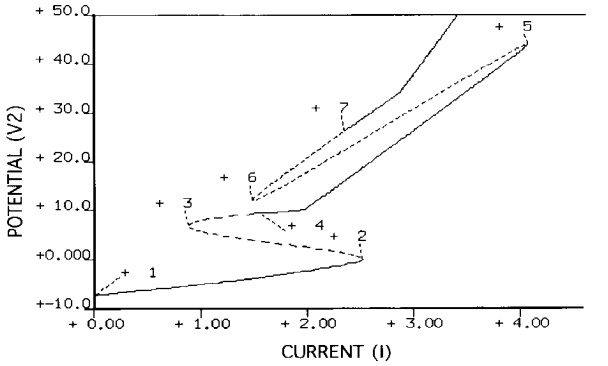

Fig. 2. Bifurcation diagram showing stationary potentials of cell 2 (V2) versus I for R=20

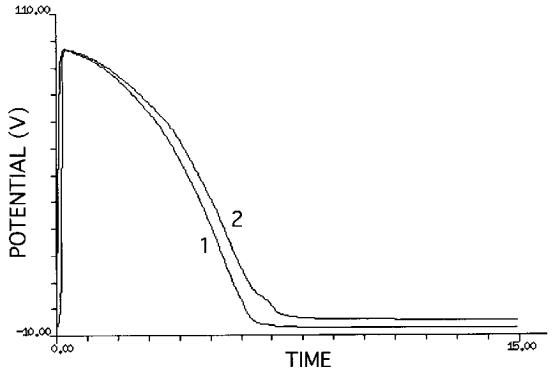

Fig. 3. Action potentials for cells 1 and 2 with depo2=10. (R=20, I in the L zone).

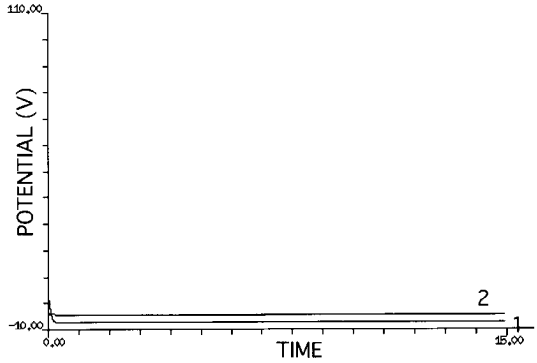

Fig. 4. Action potential of cells 1 and 2 with depo1=10. (R=20, I in the L zone).

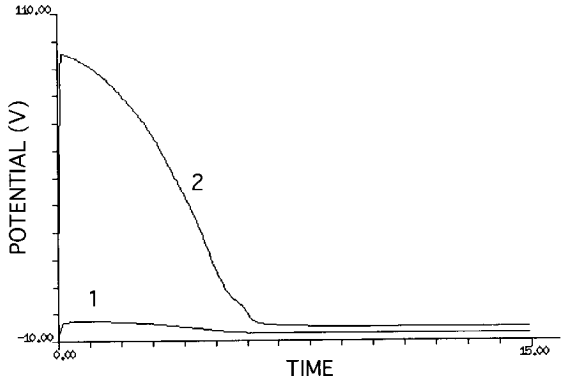

Fig. 5. Action potential of cells 1 and 2 with depo2=15 (R=50, I in the L zone)

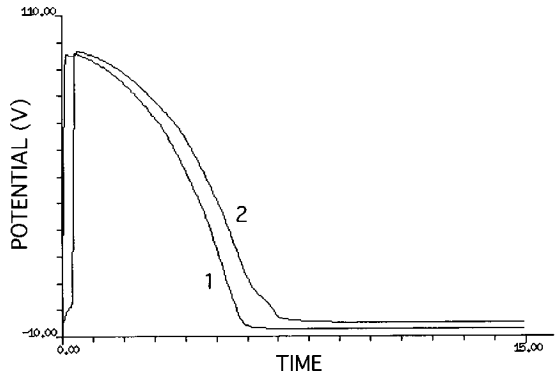

Fig. 6. Action potential of cells 1 and 2 with depo1=15. (R=50, I in the L zone).

When R is increased to 50, we found a unique threshold (depo=12). When cell 2 is depolarized above it, it results, in an AP in cell 2 non propagated to cell 1 (figure 5) or, on the

contrary, in a propagation when the same depolarization is applied to cell 1 (fig. 6).

When I is in the PB4 zone, a periodic solution coexists with a L type stationary solution. We found again a window of threshold of depolarization with a propagated AP when depolarization is applied to cell 2 but in this case, locking of the system to a rhythmic activity of mean amplitude for cell 2 and low amplitude for cell 1 (fig. 7) and a block when the same depolarization is applied to cell 1 (fig. 8).

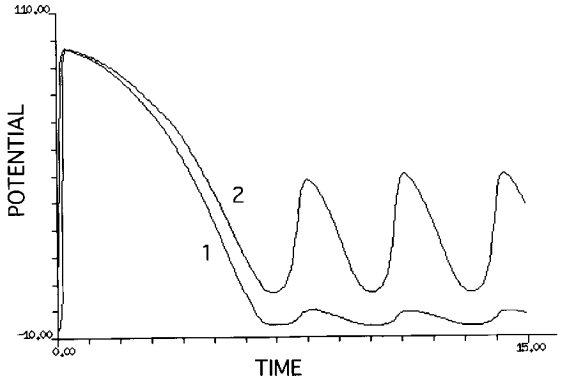

Fig. 7. Action potential of cells 1 and 2 with depo2=9. (R=20, I in the PPB4 zone).

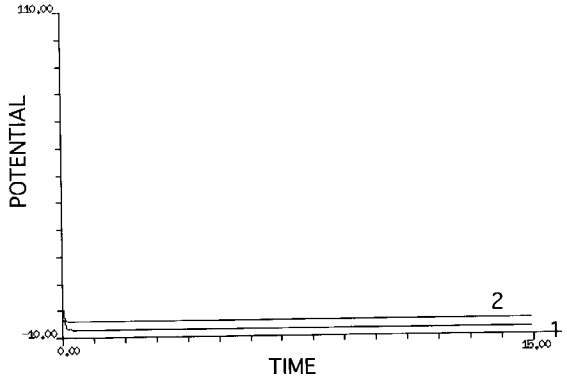

Fig. 8. Action potential of cells 1 and 2 with depo1=9. (R=20, I in the PB4 zone).

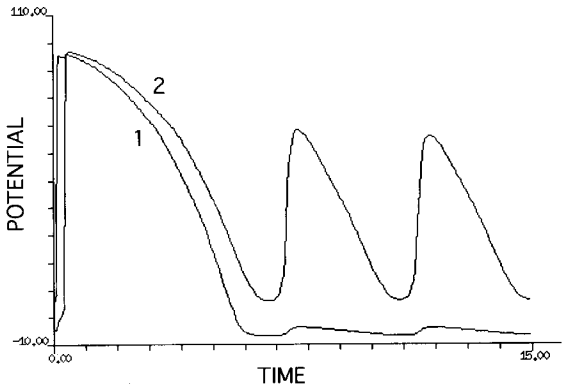

Fig. 9. Action potential of cells 1 and 2 with depo1=12. (R=50, I in the BP4 zone).

When R=50, we found a unique threshold with propagation and locking to a periodic acvtivity when the depolarization is applied to cell 1 (fig. 9) and a non propagated potential in cell 1 when depolarization is applied to cell 2 and a subsequent locking to the same periodic solution (fig. 10).

When I is in the PB7 zone, a periodic solution coexists wiyh a M type of stationary solution. We found for R=20 a window of threshold of depolarization with propagation and locking to periodic activity when depolarization is applied to cell 2 (figure 11) and a block when the same depolarization is applied to cell 1 (figure 12). When R=50, on the contrary, we have a unique threshold with propagation and block in the reverse direction (fig. 13 and 14).

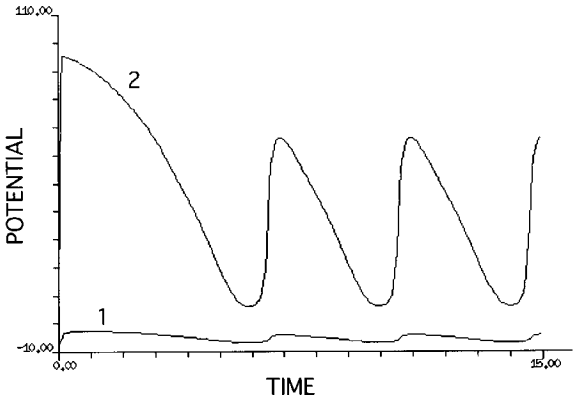

Fig. 10. Action potential of cells 1 and 2 with depo2=12. (R=50, I in the PB4 zone).

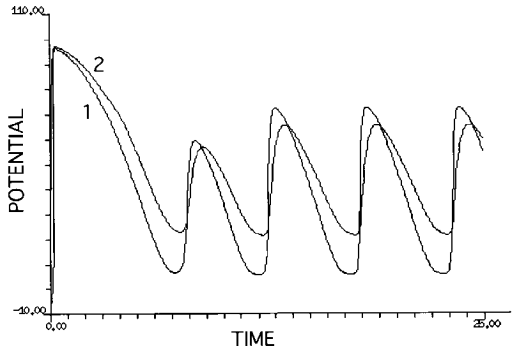

Fig. 11. Action potential of cells 1 and 2 with depo2=9. (R=20, I in the PB7 zone).

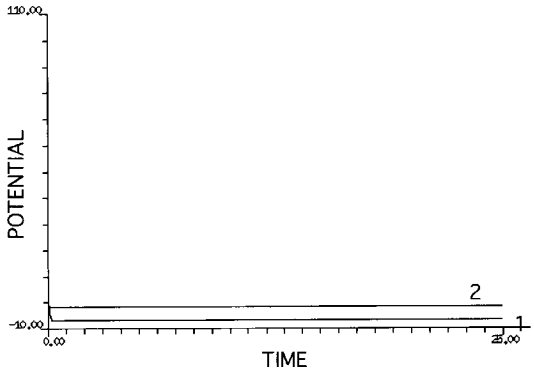

Fig. 12. Action potential of cells 1 and 2 with depo1=9. (R=20, I in the PB7 zone).

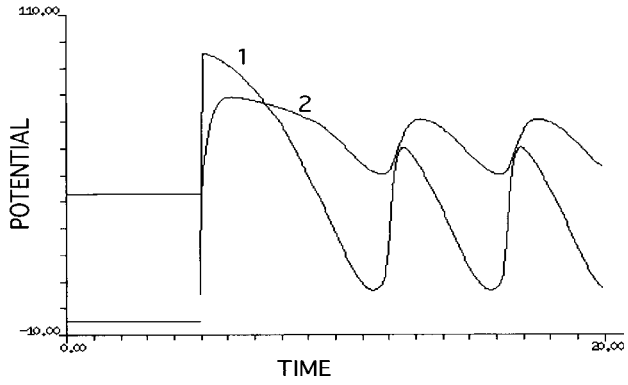

Fig. 13. Action potential of cells 1 and 2 with depo1=10. (R=50, I in the PB7 zone).

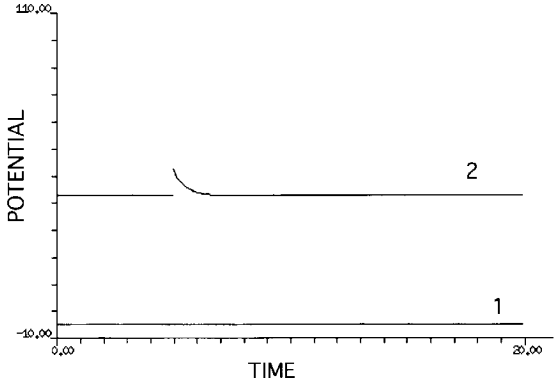

Fig. 14. Action potential of cells 1 and 2 with depo2=10. (R=50, I in the PB7 zone).

IV. Conclusion

The system of coupled NC and DC presents both heterogeneity in thresholds for depolarization and Hopf bifurcation points for critical values of the degree of ischemia. The corresponding UB and EF may be thus studied in a unified approach. The possible interplay between these phenomena and some aspects of the part of the coupling resistance for the type of depolarization thresholds necessary for UB and EF generation are evidenced.

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